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**Quantum simulations of magnetism with large numbers of atomic ion spins**[1]

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We report the engineering of the form and range of fully-connected Ising interactions and the observation of interesting spin orders in quantum simulations of magnetism with many trapped ion spins. The interaction between the spins is provided through state-dependent laser forces applied to individual ions in a laser-cooled Coulomb crystal. When such a laser force is applied globally, an effective spin-spin interaction emerges that is mediated through the collective motion of the ions. The sign and range of this effective magnetic interaction can be precisely controlled with the laser and any possible spin correlation function can be measured by imaging the state-dependent fluorescence from the ions. We simulate interesting spin models that possess nontrivial ground states for the investigation of quantum phase transitions, quantum frustration, and the emergence of spin liquid behavior. We speculate on the scaling of this system to more than 25 spins, where classical models are not able to calculate ground states or spin dynamics.

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